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Suppression of Secondary Electrons in a Dielectric Loaded Accelerating Structure

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The Problem

Efforts to transmit high rf power through the dielectric loaded accelerating tubes that are the present focus of AWA R&D have observed what appear to be secondary electron showers formed on the inner dielectric surface and by electrical breakdown in the gaps between sections of the dielectric. Bonding of dielectric sections together may prevent this latter problem, but eliminating the former problem will, in my opinion, require a different, somewhat unusual approach that I will outline below.

Source of the Problem

E-field boundary conditions in all-metal cavities are described by the requirement that the longitudinal E-field component (i.e. parallel the metal surface) "vanish". (I'm ignoring skin-depth effects, in that they do not substantially change the argument) Electron field emission is primarily and causally associated with the normal component of the E-field.

The situation in quite different in the dielectric lined tube devices that are the focus of AWA developments. In these, the longitudinal E-field along the dielectric surface is the same as that on-axis (E_0). I posit that his distinction accounts for unfamiliar electron emission and breakdown phenomena such as those observed in recent hi-power rf studies of the devices.

Visual inspection under even moderate magnification of the inner bore surface of a typical dielectric tube shows it to have considerable roughness. Simply dragging a needlepoint across the surface and feeling a "texture" can confirm this. Doing the same on a piece of glass, for instance, reveals a distinctly "smooth" surface. Figure 1 is a greatly exaggerated rendition of the dielectric tube arrangement.

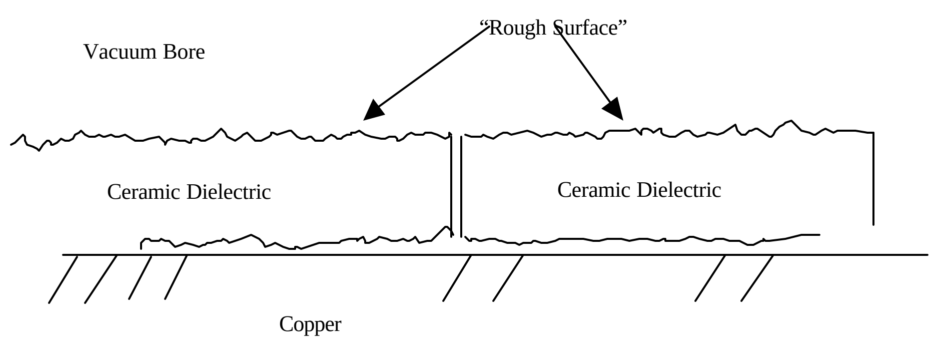


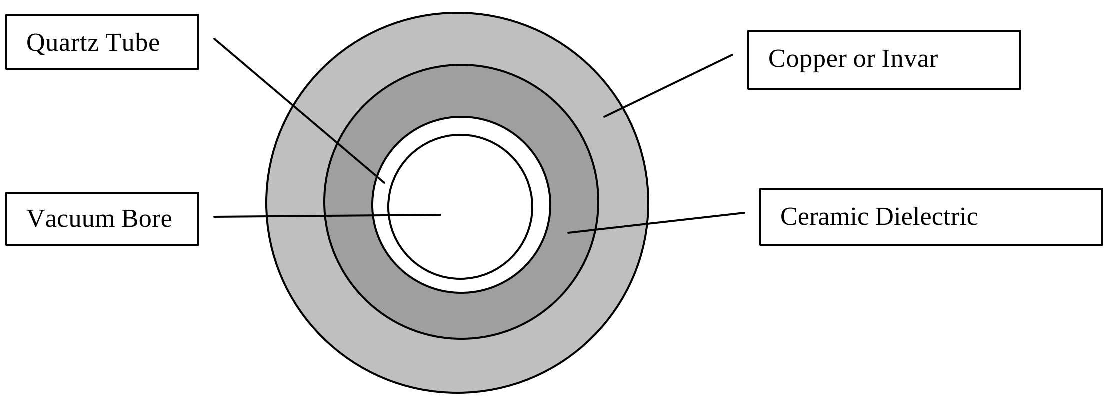
Figure 1

The small gap between pieces of dielectric can have an E-field ε times than of the E-field in the bore, almost certainly enough to be of breakdown concern. This problem has already been recognized and is currently being addressed by cementing the dielectric sections together. Now, consider the following scenario for problems at the "rough" surface.

Assume a (nearly) longitudinal TM0 E-field in the bore of several tens of MV/m (maybe 50?). An electron is somehow emitted from a "peak" in the surface roughness. That electron need travel only a few microns before it gains enough energy to cause secondary emission electron(s) either from a "glancing" interaction on a surface or from a downstream "peak". For example, an E-filed of 50 MV/m will accelerate an electron to 250 eV in only a 5-micron distance, and 250 eV is sufficient to produce secondarys from high secondary emission coefficient materials. I believe that the ceramics in use do, in fact, have high S.E. coefficients (is this not so?).

<u>A Possible Solution</u>

First, I believe that truly vitreous, specular finished surfaces will greatly reduce the probability of the preceding events. Given the mechanical properties of the ceramics used, I doubt seriously that their surfaces can me made to meet those specifications. However, precision quartz tubing does. Unfortunately, and although quartz does have relatively low loss at multi-GHz frequency, its dielectric constant (≈ 3.5) is too low for it to be a viable substitute in itself for the high dielectric constant (15-20) ceramic material. I therefore propose the following arrangement. (Figure 2)



<u>Figure 2</u>

Depicted here is a thin walled (1 mm) quartz tube surrounded by a ceramic tube assembly surrounded by a copper tube (I'll explain "Invar" in a moment). The materials would not be in intimate contact as depicted in this simple diagram, but would have "slip-fit" tolerances, perhaps a few mils. The space between the quartz and the copper is "flooded" with a low loss dielectric liquid. For now, I propose something like CCL_4 , ordinary carbon tetrachloride. High quality quartz tubing with 1 mm wall thickness and inner diameters in the 6 – 10 mm range are already commercially available.

All interstitial space (e.g.Cu-to-ceramic, ceramic-to-quartz, ceramic-to-ceramic, and fissures in the ceramic) will be flooded by CCL_4. Electrons produced in the flooded region will have insufficient mean free paths to gain enough energy to produce secondaries. Furthermore, it may be possible to use the liquid as a cooling medium. That will depend upon how much circulation can be produced. I imagine that the effective packing density of the ceramic-fluid volume will exceed 98%. Thus the effective dielectric constant will be little changed from that of "pure" ceramic.

The relative Ez field vs radius for the case inner radius of 3 mm, quartz tube thickness of 1 mm, copper bore of 5.41 mm, and frequency of 11.4 GHz is shown in the following figure (Figure 3). The assumed dielectric constants of quartz and flooded ceramic are 3.8 and 19 respectively. The shunt impedance for this configuration is about $3.2(10^7)$ ohms. A structure using only the ceramic layer with $\varepsilon=20$ and with the same inner bore diameter (6 mm) would have a shunt impedance of about $3.7(10^7)$ ohms, not significantly higher.

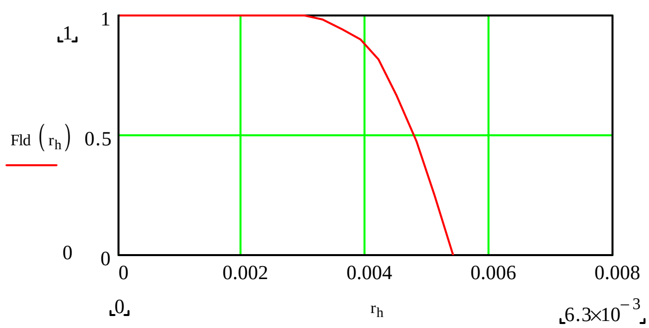


Figure 3

The addition of a quartz tube and liquids does somewhat complicate the mechanical design. Nevertheless, there are plausible solutions. Consider, for example, the input power coupling region, shown in Figure 4. Shown here is the tapered matching section between the input coupling cavity and the dielectric loaded guide.

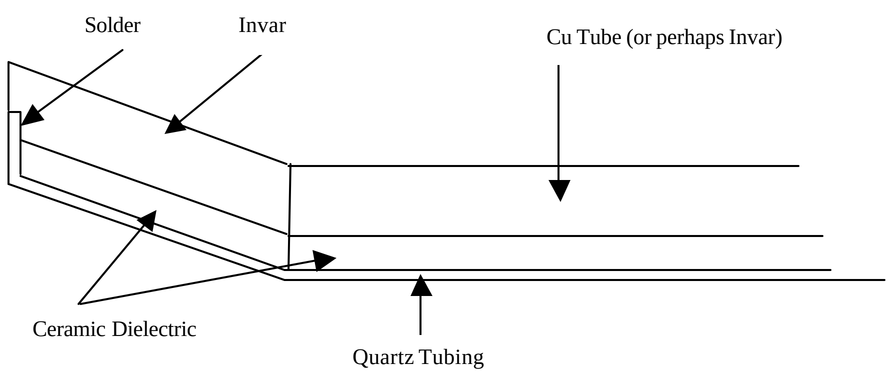


Figure 4

The input cavity (not shown) is attached to the left hand side of the assembly shown. Not indicated are holes to the ceramic region for purposes of purge/fill. The indicated solder joint is the basis for using Invar. The Invar family of alloys (usually Fe-Ni based) has remarkably low coefficients of thermal expansion. In fact, Invar's coefficient is close to that of quartz, allowing the indicated quartz-metal joint. Unfortunately, Invar is a very poor electrical conductor, so the inner surfaces must be copper plated. High power rf tests of a C-band structure has been reported [(1)], validating the idea. Instead of using copper plated Invar for the main part of the structure, it may be possible to use graded alloy sections between the Invar and copper pieces.

Practical Issues

For a SW device, an rf short at the downstream end can be easily devised. For a TW device, one must provide an output couple similar to that at the input. One possible way to overcome the obvious topological problem my be as follows:

1. Build two separate pieces, each with a coupler on one end.
2. Have the quartz tube extend a cm or so beyond the copper and ceramic at the end opposite the coupler.
3. Placing the sections back-to-back and fuse the quartz tubes together.
4. Place ceramic from a split tube around the fused section.
5. Place split copper pieces around the ceramic and sweat-solder the copper pieces together.

The quartz tube should withstand considerable external pressure. Nevertheless, it would be prudent to have fast-close isolation valves where possible to prevent contamination should there be mechanical failure of the tubing or its seals.

Care must be taken to avoid devitrification of the quartz during while shaping the cone end of the tubing and bonding (maybe forming) the disk to be soldered, and there are known procedures for that.

Comments and thoughts regarding these ideas are most welcome.

Reference(s)

(1) High Power Testing of C-band Compressor Using Low Thermal Expansion Material, M. Yoshida et.al., The 14th Symposium on Accelerator Science and Technology, Tsukuba, Japan, November 2003